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RADIATION SAFETY CRITERIA FOR PROLONGED SPACEFLIGHTS

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ABSTRACT

The authors discuss types of radiation, their energy, the dimensional dose distributions, and the RBE of ionizing radiations to be found in an Earth-lunar trajectory. The organization of a spaceflight radiation safety system is presented.

Progress in conquering space offers the prospect of longer manned /1* spaceflights, so that man and his biological complex would be exposed to excessive doses of ionizing radiation. The problem of protecting cosmonauts from cosmic radiation thus arises. The solution of problems of radioprotection in working with sources of ionizing radiation is based on many radiobiological and physical studies. It follows that analogous studies are necessary for ensuring radiation safety and establishing criteria which determine safety factors.

Principles of Guaranteeing Radiation Safety during Spaceflights

On the basis of experience in exploiting atomic power stations and the atomic icebreaker, Lenin, it can be stated that in providing for the absolute radiation safety of personnel, a special radiation safety system must be created. /2 This system necessitates the combination of physical, technical, medical and hygienic means and measures directed towards providing personnel with safe working conditions. In the structure of such a system, means of protection from

*Numbers given in the margin indicate the pagination in the original foreign text.

penetrating radiations, medical and hygienic measures, means of chemical and pharmacological protection etc. are included.

The necessity of creating a radiation safety system is fully applicable to spaceflight conditions. Due to current rigid weight-size requirements for habitable sections of manned spacecraft, it is practically impossible to create general protection from radiation which guarantees that radiation activity will be lowered to those permissible threshold dose levels accepted on earth.

In connection with this, the resolution of problems of cosmonaut protection and the provision of life support systems will probably be discovered in the course of the combined utilization of general space capsule protection, a radiation shelter, the local protection of cosmonauts, and prophylactic pharmacological and chemical agents.

A spacecraft must be provided with a system of dosimetric control designed to detect the effects of radiation on crews and biological support systems as well as to act as an alarm and warning system when radiation situations /3 deteriorate. The problems of dosimetric control on spacecraft are complex for a number of reasons. Basically, this is associated with the necessity of considering the dimensional distribution of the absorbed dose in the body of the cosmonaut, the complex spectra and composition of radiations acting on the spacecraft.

Under spaceflight conditions the possibility of there being a significant deterioration of radiation conditions as would occur, for instance, during giant solar flare activity, cannot be overlooked. Since there is a real likelihood of such an event, spacecraft should be provided with chemical and pharmacological protective agents as well as agents for treating radiation injuries (ref. 1).

Of great significance in providing for spaceflight radiation safety is terrestrial support the basic tasks of which are to pool information on radiation conditions before and during f[illegible], to forecast possible radiation effects on the bases of information on solar activity even from the spacecraft itself, and to make operational decisions in providing for cosmonaut radiation safety.

Consequently, a radiation safety system must consist of the following basic elements:

1. Radiation protection including general space capsule protection, a radiation shelter, and local protection;

2. Radiation dosimetry including on-board dosimetry, individual dose control, and an alarm and warning system;

3. Medical and hygienic measures including methods of pharmacological and chemical prophylaxis and radiation injury therapy; /4

4. Terrestrial radiation safety support.

Physical Basis of Spaceflight Radiation Safety Criteria.

The choice of radiation safety criteria is the basic problem in planning protective measures against cosmic radiation. In the majority of works [2-4] the criteria used is the local absorbed dose, e.g., the energy of radiation absorbed by one gram of tissue.

This criteria cannot be regarded as correct for a number of reasons. In the first place, the process of radiation interaction with the biological tissue in the human body takes place according to a definite dimensional distribution of absorbed dose. The dimensional distribution depends upon the spectral and angular distribution of radiation falling on the human body and consequently a coincidence of the magnitude of a local absorbed dose

with a dose absorbed in any given gram of tissue in the body can occur only in a few exceptional cases. Secondly, although a local absorbed dose might represent a radiation effect for micro objects, it can not clearly characterize the effect of radiation on large biological objects since there is an essential interdependence between injured organs and tissues, their relative radiosensitivity etc.

In our opinion, the criteria for radiation safety should be chosen in /5 terms of the spectral structure and the type of penetrating radiation acting on the human body. If the penetrating ability of radiation is high and the dose gradient within the body is small, then a mean absorbed dose value can be employed. If, however, the penetrating ability of radiation is such that in various points of the human body the absorbed doses differ sharply, then a mean dose value established for the whole body does not sufficiently reflect the magnitude of the radiation hazard, and consequently, data on the dimensional distribution of the absorbed dose must be employed.

When cosmic radiation passes through a protective layer and tissue, various secondary particles are formed (protons, mesons, emission nuclei etc.) which participate in the formation of a biological effect. The biological effect of each type of ionizing radiation depends on the magnitude of ionization losses, on what doses, and for what interval of time the radiation took place. Currently, the relative biological effectiveness (RBE) criteria is used in relation to chronic radiation. Obviously, this leads to a somewhat overestimated dose value. In the interest of obtaining more accurate data it is necessary to determine the biological effectiveness of appropriate types of radiation under conditions which most closely approximate those of spaceflight.

We will further examine the sources of radiation in space.

Galactic Cosmic Radiation (GCR)- is basically composed of protons, alpha particles, and light nuclei. The integral GCR current is 1.8-4.0 particles/cm^2.sec depending on solar activity (refs. 5-9). The angular distribution of GCR is assumed to be isotropic. The spectrum for all GCR components with energies greater than 1 bev/nucleon can be represented by an exponential function with a power of 2.0-2.5.

It appears that the consequence of the high penetrating power of GCR the dimensional distribution of dose over the body will be practically uniform. However, due to the high linear ionisation losses by heavy ions, the RBE of this radiation is high. According to our data (ref. 10), the total effect of GCR in the absence of any protection was on the order of 22 mrad/day or 130 mber/day. For an approximate evaluation of contributions by secondary radiations to the total dose arising as a result of protective measures and in the body of the cosmonaut during the action of GCR, it is possible to expedit data on the altitude dependence of ionisation in the atmosphere. It was shown that the contribution by secondary radiations was 50-100%. This dose could reach 200-250 mber/day (ref. 10) in interplanetary space. Therefore, it is obvious that GCR could constitute a serious hazard for cosmonauts during prolonged spaceflights.

In the vicinity of the earth, the GCR dose is significantly lower due to the shielding influence of Earth and its magnetic field. Thus, for orbits located at altitudes of 200-600 km at 65°, the secondary dose of GCR is 8-10 mrad/day. These data agree with those obtained from the Vostok flights (refs. 11-12).

The Inner Radiation Belt- is located within the area bounded by magnetic field lines intersecting the earth at a latitude of 45°. In the Western Hemisphere this area begins at an altitude of 500-600 km while in the Eastern Hemisphere at 1500 km. The belt extends to an altitude of 10,000 km. Peak intensity is observed at an altitude of 3600 km (first peak) and at an altitude of 7000-8000 km (second peak). The fundamental components of the belt are high energy protons (refs. 13-15).

The omnidirectional intensity of proton currents with energies greater than 40 Mev consist of $2 \cdot 10^4$ protons/cm^2.sec in the first peak and close to $5 \cdot 10^3$ proton/cm^2.sec in the second peak. The proton spectrum of the belt can be represented by an exponential function with a power from 1.4 to 1.8 depending on the section of the spectrum of protons (refs. 13-15).

The dimensional dose distribution for different thicknesses of aluminum computed for a circular (50 cm) phantom is given in Figure 1 (ref. 10). The drop in dose in this case is such that the application of the mean tissue dose would already be justified for protective thicknesses greater than 1 gm/cm^2. Mean proton dose values for various circular orbits and for a 1 gm/cm^2 aluminum layer are given in Table 1 (ref. 10).

Table 1. Mean Proton Tissue Doses (circular phantom) ber/day (ref. 10)

Altitude above earth (km)	orbital inclination plane			
	0°	45°	65°	90°
300	0.05	<0.05	<0.05	0.05
500	0.16	0.16	0.16	0.16
1000	2.0	0.9	0.65	0.58
2900-3500	110	26	20	18
7500	2.6	3.4	2.6	2.4

The Outer Radiation Belt is made up of electron currents. The belt is situated in an area 10,000-50,000 km above the equator and extends down to 300 km between latitudes of 55° and 70°. The peak intensity in the outer belt occurs at 15,000-20,000 km. In this area, electron currents with energies greater than 40 kev contain nearly 10^8 particles/cm^2.sec. The spectrum of electrons in the outer belt can be represented by an exponential function with a power of 2 ± 0.5. The angular distribution of electrons in the outer belt is assumed to be isotropic (refs 6, 16).

The electrons of the outer belt have a low penetrating ability and would primarily effect the skin. In the center of the belt, if provided with a protective covering of light material (1 gm/cm^2), the dose power at the surface of the body, 40 rad/day, has been established in another study (ref. 17). The mean tissue dose , determined by bremsstrahlung and established by a method given in another study (ref. 18), would then be 1 rad/day.

The Artifical Radiation Belt, formed as a result of high altitude atomic explosions, consists of electrons with energies up to 7 Mev. The dimensional distribution and currents of electrons are changing with time. The most stable portion (with a constant decay of 1-3 years) is situated at a distance of 1200-4500 km above the equator. In the center of the artificial belt at an altitude of 1800-2300 km the omnidirectional intensity of electrons with energies greater than 0.5 Mev was composed of 1·[illegible] particles/cm^2.sec (ref. 15) at the end of 1962 (refs. 5-10).

In Table 2, the surface dose values of electrons in the artificial belt determined by us for protection of 1 gm/cm^2 according to a method given in another paper (ref. 17) are given.

The dose from bremsstrahlung with a protective layer of 1 gm/cm^2 is significantly less than the dose from electrons. The dimensional distribution of dose from electron bremsstrahlung in the center of the artifidal belt calculated for a circular phantom 50 cm in diameter is given in Figure 2.

Table 2.

Surface Doses of Electrons in the Artificial Belt rad/day (in 1962)

Altitude above Earth, km	orbital inclination plane 0°	45°	65°	90°
1000	3.10^3	6.10^2	$4.5 \cdot 10^2$	$4.2 \cdot 10^2$
1800-2300	2.10^5	$2.4 \cdot 10^4$	$1.9 \cdot 10^4$	$1.7 \cdot 10^4$
3000	$4.4 \cdot 10^4$	$8 \cdot 10^3$	$6.5 \cdot 10^3$	$5.9 \cdot 10^3$
8000	$2.8 \cdot 10^3$	$7 \cdot 10^2$	$5.5 \cdot 10^2$	$5 \cdot 10^2$

Electrons of radiation belts have a high dose drop rate as a function of depth. Consequently, it is more appropriate to employ the maximum (surface) dose when determining radiation safety criteria.

Solar Corpuscular Radiation (SKR) arises as a result of chromospheric flares on the sun. The frequency of solar flares depends on solar activity. In a period of maximum solar activity during a year, nearly 5-13 flares of moderate intensity occur while in a period of minimum activity flare frequency decreases. Solar flares emitting high intensity radiation occur 1-2 times in 5 years. In the present period of minimum solar activity (1964-1966) solar flares are extremely infrequent but their frequency will increase during the period 1969-1970.

Solar flare corpuscular radiation basically consists of protons and alpha particles. When there is a protective layer greater than 3-5 gm/cm^2 the contribution from alpha-particles would be small. The spectrum of protons

from solar flares consists of particles with energies ranging from a few Mev to tens of Bev. As a consequence of this, there are significant dose fluctuations in different parts of the body when protective layers are slight (Fig. 3). As the thickness of a protective layer becomes greater, the filtration of high energy protons and dose fluctuations in the body decrease.

In Table 3, dose values in a spot target and in a circular phantom behind a 1 gm/cm² aluminum protector calculated according to a method given in another work (ref. 19) are presented.

Table 3.

Radiation Doses of Some Solar Flares, rad per flare

Date of Flare	Spot Target	Circular Phantom
23/2/1956	560	82
12/11/1960	2200	90
10/5/1959	8600	270

Radiobiological Investigations

Of great importance in resolving problems of radiation safety during space-flights will be radiobiological investigations.

The fundamental problems of these investigations is to obtain information on the relationship between the damaging effects of cosmic radiation and the energy and type of radiation, the dose power, the dimensional distribution of absorbed dose. In addition, it will be important to study injuries to critical organs and the existence of reparatory and compensatory processes taking place in the organism as a result of repeated and chronic irradiations. The solution of these problems will permit the substantiation of acceptable radiation levels for crews and recommendations when they are surpassed. Furthermore, they will be precursors to finding effective prophylactic and therapeutical

agents.

The RBE of Cosmic Radiations. At the present time, it is not yet possible to generalize the RBE relationship for all components of cosmic radiation. First of all, this is due to the fact that there is considerable technical difficulty in simulating the energies of certain types of cosmic radiation under terrestrial conditions. The well-known difficulties in determining the RBE of cosmic radiations are also due to the imperfections of tissue dosimetry which do not permit an accurate evaluation of absorbed energy or make corresponding comparisons feasable. Also, experimenters are confronted with many complex problems in evaluating a number of factors which could significantly affect biological effectiveness. In particular, RBE can vary according to the investigated biological specimen, the species of plants and animals, the and effect under study (radiation damage to skin, hematopoietic structures, the crystalline lens, the nervous system etc.). Particularly significant variation occurs when evaluating genetic changes. The RBE under similar conditions can vary depending on whether the effects of the single acute action is being considered or whether the manifestations of chronic or fractional radiation are being evaluated. /13

Already for a number of years, investigations in the USSR have been conducted to determine the peculiarities of radiation injuries produced by protons and to ascertain the RBE of protons (refs. 20-23).

Experimental animals (dogs, rats, and mice) were exposed to proton radiation from a synchrocyclotron in the Laboratory of Nuclear Problems, OIYAI in Dubna. The establishment of an RBE coefficient for protons was accomplished by comparing the viability of animals and the severity of radiation injuries as a result of exposure to protons, x-rays or gamma rays.

In experiments on dogs, the effects of radiation were considered as a function of their general condition, morphological and biochemical composition of the peripheral blood, the condition of the cardiovascular system, immunological reactivity, and morphohistological investigations.

In experiments on dogs (refs. 21,22) it was shown that irradiation by 126, 240, and 510 Mev protons led to the development of radiation injuries which were basically characterized by the normal acute radiation sickness produced by "standard" forms of radiation. However, along with the similarity or uniformity of injuries evoked by proton irradiation were differences. First of all, destructive changes in the vasculature of all animals were more sharply pronounced. As a result of this, hemorrhagic manifestations were more severe. Hemorrhaging was observed in earlier stages in a large number of animals. Also, characteristic of hemorrhages was their unusual localization. Another difference was a more severe inhibition of bone marrow blood formation, especially erythropoiesis.

Conclusions on the RBE of protons were drawn on the basis of detailed clinical studies on radiation injury as well as comparisons of fatal effects. The RBE coefficient when dogs were exposed to multiple doses of 126 and 510 Mev protons was found to be on the order of 1.0. Upon single exposure, the value increased to 1.2 for 510 Mev protons and fell to 1.0 for 126 and 240 Mev protons (Table 4).

Table 4.

RBE Coefficients of Protons with Energies of 126-510 Mev

Type of Animal	Character of Radiation	Proton Energy(Mev)	Observed Effect (criteria)	RBE
Dogs	19 exposures for 5 weeks	510	Death, Longevity, Hematological shifts	1.0
Dogs	"	126		1.0
Rats	20 exposures for 5 weeks	510		0.8
Dogs	one exposure	510	"	1.2
Dogs	" "	240	"	1.0
Dogs	" "	126	"	1.0
Rats	" "	510	LD 50/30	0.75
Rats	" "	240	"	0.73
Rats	" "	126	"	0.80
Mice	" "	240	"	0.65
Mice	" "	126	"	0.55

In parallel investigations conducted on small laboratory animals it was shown that the biological effectiveness of 126, 240, and 510 Mev protons in rats and mice was somewhat less than that of gamma rays (cobalt-60).

The above remarks relating to the problem of RBE are concerned with establishing the biological effectiveness of cosmic radiations for animals and man. However, in connection with the proposed use of higher and lower plants in space capsules as life support for long spaceflights, the problem of establishing radiation norms for plants and determining the RBE of cosmic radiations applicable to plants is also of foremost significance.

It is highly unfortunate that up to the present time the problem of the RBE of various types of ionizing radiation with respect to plants has

not been considered to be as acute as it has with animals. The available literature has been primarily devoted to determining the RBE on the basis of genetic effects in comparing the action of neutrons with x-ray or gamma radiations. Investigations with plants concerning the RBE of protons are practically non-existent.

Investigations conducted by us in determining the RBE coefficient of 126 and 660 Mev protons on seeds of Chinese leaf cabbage showed that the somatic effect under a wide dose range (500-500,000 rad) reflected an RBE value of 1.6-2.0. Other results have been obtained by determining the RBE on the basis of computing chromosome aberrations in the primary rootlets of cabbage seeds. Under doses up to 10,000 rad, the RBE coefficient was on the order of 1.0 followed by a gradual increase to 2.2 and 2.0 for protons with energies of 126 and 660 Mev at doses of 21,000 and 100,000 rad respectively. It is interesting to note that the RBE of 660 Mev protons at a dose of 21,000 rad was 1.2, e.g. 126 Mev protons were more effective than 660 Mev protons by a factor of 1.9. The results indicate that protons with the given energies were more effective against plants than animals.

Therefore, analysis of available data on the RBE of various types of cosmic radiation indicates the need for similar types of investigations, especially with protons of various energies and highly charged ions, in that such information is essential in evaluating the radiation hazards for a number of higher and lower plants to be included in the life support systems of future interplanetary spacecraft.

Critical organs. Together with the establishment of the RBE of cosmic radiations, a most important aspect of radiobiological investigations must be the study of the biological effect of various dimensional distributions of

of absorbed energy. The wide energy spectrum of cosmic radiations means that the depth of dose absorption varies. This, in turn, necessitates evaluating the radiation hazard arising from injuries to so-called "critical organs" in a manner analagous to what is currently being done when the interior of the organism is exposed to radioactive substances.

It is reasoned that those particular conditions characteristic of spaceflight require the introduction of additional information to existing views on "critical organs". It would seem that together with those accepted critical organs (bone marrow, gonads, skin, the crystalline lens etc.) the vestibular analyzer should be included. This is primarily dictated by the fact that under spaceflight conditions, this analyzer is exposed to such stimuli as linear, angular, and Coriolis accelerations. Furthermore, it functions under conditions where analyzer interaction is disrupted in addition to changes in impulsation from the otolithic mechanism, proprioceptors and other sensitive systems under conditions of partial or complete weightlessness. The disruption of vestibular activity might be the cause of stress reactions and other vestibular-autonomic and somatic disorders.

As our investigations on 600 rabbits have shown, the statokinetic analyzer is extremely sensitive to ionizing radiation (refs. 24-27). When rabbits were given whole body irradiations of 50-100 rad, the excitability of this analyzer increased in the first hour after exposure. At a dose of 500 rad and greater reflex activity was lowered and there was an inhibition of vestibular-autonomic and vestibular-somatic reflexes.

The permissible level of radiation. A necessary link in providing for radiation safety during spaceflights is the establishment of permissible cosmic radiation levels during the time of the flight. Clear, scientifically

based regulations on permissible radiation levels will essentially predetermine the character of the resolution of many problems.

As it is known, at the present time in the USSR, USA, and other countries, established threshold permissible levels for people working with external and internal sources of ionising radiation are 0.1 ber per week or 5.0 ber per year. The existing radiation norms as a rule are determined by industrial technology, protective devices, and the possibility of evacuating the worker to other industrial sections not associated with the action of radiation when he is over irradiated etc.

However, considering the physical peculiarities of cosmic radiations (composition, intensity, spectral and energy characteristics), the computed data indicates that prolonged spaceflights (to Mars, Venus, and other planets) will doubtless expose cosmonauts to ionising radiations in doses which significantly exceed 5.0 ber per year. Consequently, those norms established for working with terrestrial sources of ionising radiation are not applicable to spaceflights. Therefore, new approaches are necessary for establishing /20 permissible radiation levels for space crews applicable to long spaceflights.

Conditions for establishing spaceflight radiation safety in ouropinion requires that doses of ionising radiation be divided into 3 groups:

-permissible doses (p d)

- justified risk doses (j r d)

- critical doses (c d)

The permissible dose-that dose of ionising radiation which, according to current data, does not cause any permanent somatic damage. These doses can be recommended as norms for short spaceflights. Exposure to radiation in excess of the norms can be prevented by physical protection and the selection

of special orbits.

The justified risk dose-that dose of ionizing radiation which, according to current data, can only lead to weakly pronounced clinical manifestations of radiation injury in a few cases. These doses can be recommended for prolonged spaceflights where the biologically active absorbed dose will fundamentally be due to galactic cosmic radiation.

The critical dose-that dose of ionizing radiation which, according to current data, can lead to severe clinical manifestations of radiation injury. The absorption of such a dose by the cosmonaut must act as a signal for therapeutical, prophylactic, medical intervention. /21

In our opinion, these dose classifications are extremely necessary taking into consideration the different character, mission, and duration of spaceflights.

One of the next steps in mastering space will probably be a flight by man to the moon. This flight, from the point of view of physical and radiobiological evaluation of radiation hazard, will be far more complicated than the past orbital flights of the Vostok and Voskhod series and therefore demands special attention.

According to calculated data, a flight to the moon and back will not exceed 10-15 days (ref. 22). The crew of such a lunar flight will be exposed to galactic cosmic radiation, radiation from belts surrounding the Earth, and radiation from solar flares should they occur during the flight.

In evaluating the radiation hazard, we feel it expedient, first of all, to shape the following situations which must be considered as the basis for recommending permissible doses for spaceflights to the moon.

In the first place, the physical parameters of galactic cosmic radiation and solar flare radiation are such that the creation of protection which

would almost entirely absorb ionizing radiation is even theoretically unrealistic. Therefore, cosmonauts on lunar flights would be irradiated in doses which would exceed normal terrestrial levels. In this connection, notwithstanding that the biological effect of ionizing radiation might be threshold or not, the summary dose even from galactic cosmic radiation would be biologically active. Therefore, in developing radiation protection it is /22 important to consider sensible approaches to the organization of all systems of radiation safety taking into account realistic technical possibilities. Of course, in evaluating the radiation hazard of a moon flight and in allowing for a permissible risk, we must consider the existing knowledge on the biological effects of ionizing radiation and the technical feasabilities of spaceflight security.

In the second place we consider it appropriate to allow for the fact that in spaceflights to the moon (15 days), the possible total irradiation of cosmonauts by galactic cosmic radiation, radiation belts of the Earth, and solar flares can be evaluated as a single irradiation.

In the third place it is important that space crews of future spaceflights not be exposed to any additional irradiation in connection with professional duties.

In the fourth place, the unusual conditions in question are determined in the light that only a very limited number of people will be exposed to irradiation.

From our considerations of the specific features of short-term spaceflight, of the irradiation of a limited number of people, of a single, unique "professional irradiation, and of the many years of investigations by radiobiologists on evaluating the biological effectiveness of ionizing radiation on man and

experimental animals, it is possible to propose a dose of 15 ber as a reference value in developing a radiation safety system for a spaceflight to the moon.

The evaluation of the radiation hazard for prolonged spaceflights and the establishment of acceptable dose values which would guarantee the health and working ability of cosmonauts is a complex problem. This complexity is /23 determined by the following factors:

1. The paucity of data on dose values and the distribution of dose at the actual time of spaceflight (most published results have been obtained by means of estimation).

2. The far from sufficient knowledge of the specific features of the effects of different kinds of radiation and their RBE.

3. The lack of factual material obtained by modeling radiation effects applicable to prolonged spaceflight (chronic effect of radiation over a period of 2-6 years including the simultaneous effects of single, periodic, repeated irradiations).

4. Lack of data on recovery mechanisms due to radiation injuries under conditions of the repeated action of ionizing radiation.

5. Essential restrictions in the extrapolation of results obtained in experiments with animals to man.

Therefore, any evaluation of doses or recommendations thereof will be of an approximate nature. Only through the accumulation of knowledge and the /24 introduction of corresponding revisions will the separation between preliminary recommended acceptable dose values and their true values be minimized.

In considering the radiation hazard and allowable doses of ionizing radiation for long spaceflights (several years), our knowledge at the present

Depth dependence of the absorbed tissue dose for different thicknesses of aluminum

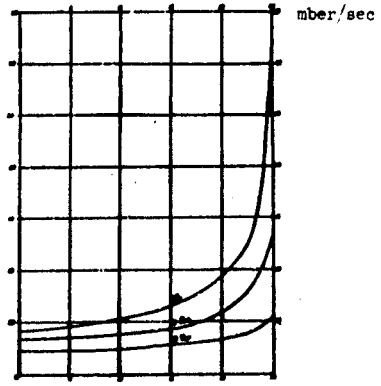

Figure 1. Dimensional distribution of absorbed proton dose from the inner radiation belt in a circular phantom (R = 25 cm) for different thicknesses of aluminum protection.

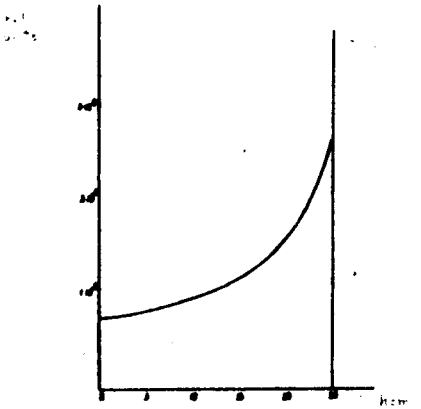

Figure 2. Dimensional distribution of absorbed tissue dose from electron bremsstrahlung in the center of the artificial radiation belt.

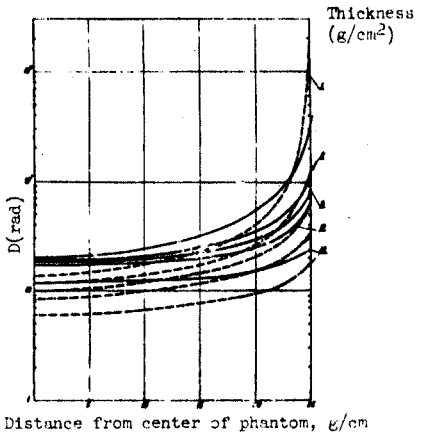

Figure 3. Dimensional distribution of absorbed tissue dose in a circular phantom (R=25 cm) for different thicknesses of of aluminum protection.

_____ solar flare, 23 Feb. 1956

---------- solar flare, 12 Nov. 1960

time concerning the radiation situation in space and the biological effects of radiations makes it more expedient than ever to speak of allowable risk doses.in that,the absorbed dose from galactic cosmic radiation alone will significantly exceed the permissible dose value, 15 ber, which we recommended for shorter spaceflights.

CONCLUSIONS

In summing up, it should be observed that in the course of resolving the problems of spaceflight radiation safety, there are many unclear questions. The successful accomplishment of cosmonaut protection during prolonged spaceflights will on one hand depend on how clear determinations of radiation hazard criteria are and on the other how effectively the fundamental problems of creating a radiation safety system will be resolved. The latter would include problems of protection, dosimetric control, prophylaxis and treatment of radiation injuries, determining the biological peculiarities of the effects of cosmic radiation under terrestrial conditions and during combined and other spaceflight factors. There is no doubt that only through such a complex approach will the necessary prerequisites for resolving all problems to this end be created.

REFERENCES

1. Genin, A.M., Gurovskiy, N.N., Yemel'yanov. M.D., Samsonov, P.P., and Yazdovskiy, V.I. Man in Space (Chelovek v kosmose) , Medgiz, 1963

2. Day, D.L. and Noyes, J.C. Journal of Astronautical Sciences, no.3, 1960

3. Beck, A.J. and Divita, E.L. American Rocket Society Journal, Vol. 32, 1962, p. 1668

4. Reitz, D. Aerospace Engineering, Vol. 20, 1961, p. 28

5. Vernov, S.N., Chudakov, A.Ye., Vakulov, P.V. and Logachev, Yu.I. Doklady AN SSSR, Vol. 125, No.2, 1959, P 304

6. Vernov, S.N. and Chudakov, A.Ye. Achievments of Physical Sciences (Uspekhi fizicheskikh nauk), Vol. 70, No.4, 1960, p. 585-619

7. Van Allen, J.A. and Frank, L.A. Nature, Vol. 183, 1959, p. 430

8. Kurnosova, A.V. et al Artificial Satellites of the Earth (Iskustvennyye sputniki zemli),no.5, 1960, p.30

9. Ginsburg, V.L. and Syrovatskiy, S.I. The origin of Cosmic Rays (Proiskhozhdeniye kosmicheskikh luchey), Moscow , Izdatel'stvo AN SSSR, 1963

10. Dudkin, V.Ye., Koval', Ye.Ye., Smirennyy, L.N., and Sychkov, M.A. Problems of Dosimetry and Radiation Protection. Collection of articles (sb. Voprosy dozimetrii i zashchity ot izlucheniy), No.3, Moscow, Atomizdat, 1964, p. 174

11. Keirim-Markus, I.B., Kovalev, Ye.Ye., and Uspenskiy, L.N. Artificial Satellites of the Earth (Iskusstvennyye sputniki zemli), No. 12, 1962, p. 47

12. Keirim-Markus, I.B. et al Artificial Satellites of the Earth (Iskusstvennyye sputniki zemli), No. 15, 1963, p. 102

13. Van Allen, J.A., and Frank, L.A. Nature, Vol. 183, n4659 , p. 430 (1959)

14. McIlwain, C.E. Science, Vol. 142, n3590, 1963, p. 355-361

15. Freden, S.C. and White, R.S. Journal of Geophysical Research, Vol. 67, 1962, p. 25

16. O'Brien, B. and Van Allen, J. et al Radiation Belts of the Earth. Collection of articles (sb. Radiatsionnyye poyasa Zemli). Moscow, IL, 1962, p. 72

17 Radziyevskiy, G.B. and Osanov, D.P. Problems of Dosimetry and Radiation Protection. Collection of articles (sb. Voprosy dozimetrii i zashchity ot izlucheniy), No. 3, Moscow, Atomizdat, 1964

18. Osanov, D.P., Kovalev, Ye.Ye. and Radziyevskiy, G.B. Ibid, p. 139

19. Dudkin, V.Ye., Kovalev, Ye. Ye., Smirennyy, L.N. and Sychkov, M.A. Problems of Dosimetry and Radiation Protection (sb. Voprosy dozimetrii i zashchity ot izlucheniy), No.3, Moscow, Atomizdat, 1964, p. 168

20. Letavet, A.A. and Kurlyandskaya, E.B. editors. Materials on the biological action of high energy protons (Materialy po biologicheskomu deystviyu protonov vysokikh energii). Moscow. AMN SSSR, 1962

21. Grigor'yev, Yu.G., Dorenskaya, N.G., Domshlak, M.P., Lebedinskiy, A.V., Nefedov, Yu.G. and Ryzhov, N.I. Features of the Biological Action and RBE of High Energy Protons(Osobennosti biologicheskogo deystviya i OBE protonov vysokikh energii v kn.)

22. Nefedov, Yu.G., editor Problems of Radiation Safety in Spaceflights (Problemy radiatsionnoy bezopastnosti kosmicheskikh poletov). Atomizdat, 1964

23. Sisakyan, N.M., Parin, V.V., Antipov, V.V., Dobrov, N.N., and Saksonov, P.P. Izvestiya AN SSSR, seriya biologicheskaya, Vol. 3, 1964, p. 341

24. Sveshnikov, A.A. Meditsinskaya radiologiya, No. 9, 1963, p. 49-51

25. Sveshnikov, A.A. and Sevan'kayev, A.V. Problems of Space Biology. Collection of articles. (V.sb. Problemy kosmicheskoy biologii), Vol. 3, Moscow. Izdat. Nauka, 1964, p. 355

26. Grigor'yev, Yu.G., Sveshnikov, A.A. and Sevan'kayev, A.V. Problems of Radiation Safety in Spaceflights . Collection of articles (V kn. Problemy radiatsionnoy bezopastnosti kosmicheskikh poletov. Nefedov, Yu.G. editor), Atomizdat, 1964, p. 157-183

27. Nesterenko, V.S. Radiobiologiya, Vol. 4, no.4, 1964, p.643

28. Volynkin, Yu.M., Antipov, V.V., Guda, V.A., Nikitin, M.D.and Saksonov, P.P. Biological Evaluation of Radiation Conditions in an Earth-Moon Route. Report presented at the 15th International Astronautical Conference. Warsaw (Biologicheskaya otsenka radiatsionnykh usloviy na trasse Zemlya-Luna. Doklad na XV Mezhd. astronavt. konferents'i. Varshava), September, 1964